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RECENT EXPERIMENTAL EFFORTS IN STORE SEPARATION AT DTNSRDC

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ABSTRACT

In the early 1960's much of the philosophy and procedures
used today for captive trajectory testing was developed at
the David W. Taylor Naval Ship Research and Development
Center (DTNSRDC). After limited use of these procedures in
the late 1960's and early 1970's, the system was inactive for
several years. In the past few years, work in this area has
been restarted, and several programs have been completed.
The support system has been used in the captive trajectory
(CTS) mode, grid mode, and pressure survey mode. Extremely
good agreement has been seen for CTS data when compared with
flight test results. These data have been used to guide
flight test planning and to study control system
acceptability. Grid data, collected on several stores,
provided the means to investigate control systems and to
parametrically examine other launch variables. In addition,
pressure field data have been generated in support of
analytical separation programs. In some cases, scale
·problems were encountered and have been successfully solved.

INTRODUCTION

From the time aircraft were first pressed into service as launching
platforms for weapons, there have been problems with safely launching or firing
those weapons. The firing of a gun through a propeller and the release of bombs
so as not to damage wing struts, landing gears, or empennage are examples of
early problems encountered. Generally, these problems were solved by modifying
flight hardware or by some change in flight procedures. However, as the use of
aircraft for this purpose increased and, more importantly, the use of external
carriage increased, the seriousness of this problem became greater. In
addition, the increase in flight speed as technology progressed compounded the
problem by imposing greater loads on the weapons and carriage equipment.

Another important factor which added more complexity to this problem was the
larger number of aircraft configurations and weapon carriage arrangements being
introduced. Several wing planforms became common place. Weapons carriage at
many stations on the wings and fuselage using several multiple carriage racks
appeared. These various configurations produced many different types of air-
flow in which weapons had to be launched. The carriage and launch equipment
add more variation to this problem by affecting this airflow in different
ways and by providing different ejection characteristics during launch. In
addition to these aircraft-related differences, the weapons presented a wide
range of mass properties and aerodynamic stability characteristics. From very
low density articles, such as fuel tanks, to very dense general purpose bombs,
the full range of mass properties were encountered. Also, stability of the
weapons during launch varies greatly from instability to very stable.

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This severe environment and the greater number of different weapon configurations made it very difficult to predict with which weapon and under what conditions a problem would develop. Therefore, it became necessary to conduct extensive flight testing before a weapon was introduced to the operating forces. Since most other flight problems had been successfully solved with sub-scale models in wind tunnels, methods were developed to study weapon separation in the same fashion. These testing techniques fall into four basic catagories: dynamic drop, computer/tunnel trajectory simulation, grid data survey, and flow field mapping. Although dynamic drop testing is done in the wind tunnels at DTNSRDC, this paper will concentrate on the other methods.

These methods, computer/tunnel trajectory simulation or captive trajectory method, grid data survey, and flow field mapping, use a dual support system. Much of the early work to develop the concept and the mathematics for these testing techniques was done at DTNSRDC in the late 1950's and early 1960's.[1,2] These reports address both the use of a computer controlled captive trajectory system (CTS) and the use of grid data collected using a weapon model in the flow field of an aircraft. These pioneering efforts led to the development of a dual support system in the 7- by 10-foot transonic wind tunnel at DTNSRDC. This system was used on several test programs during the early 1960's, but was hampered by mechanical problems and the lack of computer facilities. In the late 1960's a new support system was obtained, increased computer capability was purchased, and new software was developed. With these new components several successful programs were conducted in the early 1970's. Grid data for comparison studies[3,4] were produced with this system as well as a separation of the HARPOON from the P-3.[5] For several years, the system was used very little with only one study reported.[6]

In the late 1970's, a commitment was made to reactivate and update the system for use in Navy programs. These efforts will be discussed in this paper to summarize the recent developments and to illustrate the capabilities of the present system. These efforts include CTS testing, grid data generation, and flow field mapping using flow angularity probes.

DESCRIPTION OF TESTING TECHNIQUES

The three testing techniques presented use the dual support system in the 7- by 10-foot transonic tunnel. An aircraft model is mounted inverted on the main support system. Either a weapon model or a flow angularity probe is mounted on an auxiliary support system, and this support system allows access to the volume beneath the aircraft model. A typical installation is shown in Figure 1. The following sections describe the procedures for using the system with the various test techniques.

CAPTIVE TRAJECTORY SYSTEM (CTS)

When using the CTS technique, the support system is on-line with a computer in a closed-loop operation. The tunnel is brought to the desired Mach number and the aircraft model set to desired attitude. The weapon or store is then manually placed in the position where the trajectory begins. This initial point can be a stowed position or another position where motion parameters are known.

From this initial point, data are read from the balance in the weapon, and aerodynamic forces are computed for full-scale conditions of the launch. In these calculations, aerodynamic forces are adjusted for scale and altitude. The forces and moments due to dynamics, ejectors, thrust, and controls are computed and added to the adjusted aerodynamic forces and moments. With these forces, the equations of motion are solved, and the motion of the store is predicted. The support system is then placed under computer control, and the store is moved by the computer to the predicted position in the flow field. In determining the location of the store in the tunnel, sting deflection and aircraft movement are accounted for. This process is continued until safe separation is demonstrated or the weapon contacts the aircraft. In addition to the Mach number and altitude conditions, the software can account for the attitude of the aircraft flight path, vertical acceleration by the aircraft, and accelerations of the aircraft along the flight path. Throughout this interactive process, the computer is continually checking tunnel conditions, balance loads, and data accuracy to ensure accurate trajectory simulations.

GRID DATA COLLECTION

To compute a trajectory using grid data, a two-step process is utilized. Force and moment data are collected from a balance in a weapon throughout a volume beneath the launch position on the aircraft. The size and location of this volume is selected to contain the expected trajectory of the store when launched. This collection of data, or grid of data, is then used as input to a six-degree-of-freedom trajectory program and interpolated as necessary. As with the CTS technique, these data are corrected to full-scale conditions, and other forces and moments are mathematically accounted for.

The collection of these data can be done with two procedures at DTNSRDC. The first is a mechanical system which sweeps the store in vertical planes taking data on a time trigger at random positions in the flow. By manually changing the attitude and starting location, an entire volume can be covered. These data will not be recorded at any prescribed location in the aircraft flow field, and if the computer program to use these data is designed for data in specified location, another step of interpolation is required. The other method employed for collecting data resolved this problem by having the computer on-line to position the model and account for deflections and aircraft attitude. In many cases, software which makes use of grid data is designed to work with data at specific points relative to the aircraft. It is, therefore, imperative to have this computer controlled acquistion system.

FLOW FIELD SURVEY

Obtaining data in a flow field survey is similar to ge...ating a data grid. For a flow survey, an angularity probe is used in place of a store, and the flow velocity (speed and direction) at points in the aircraft flow field is recorded. This information can then be used to calculate forces and moments on a weapon in the flow or to verify or correct analytical prediction of flow parameters. Generally, these data are taken using the computer control technique, as opposed to the mechanical system, since specific locations are desirable. In addition,

the technique using the mechanical system for taking grid data records data while the support system is moving in the vertical plane. This movement has little effect on the balance readings; however, for pressure measurements, errors may result from the reaction time of the measuring system.

RESULTS OF RECENT EFFORTS

In recent years, several test programs have been completed using the dual support system in various modes. During that time, changes have been made to accommodate tunnel power restrictions and data requirements. These changes have increased data rates and added versatility to the testing capabilities. These changes were made to take advantage of the experience gained from previous testing and to minimize restrictions imposed by power limitations. The results presented were selected to illustrate these changes and to show examples of the work performed.

HARPOON MISSILE SEPARATION

An example of the use of the support system in the CTS mode is the separation study of the HARPOON missile from the A-6E aircraft. This program provided an opportunity to exercise many changes to the CTS software, and later a flight test provided data with which a correlation study was performed. In the wind tunnel study, launches from both wing stations were performed with various loadings of fuel tanks and HARPOON's on the other stations. Variations of Mach number, altitude and flight path angles were studied as well as aircraft load factor. The primary objective of the test was to provide information to aid in the planning of a flight test program. A secondary objective was to determine if the roll authority of the control system was sufficient to stabilize the missile in roll when the control system was activated. This was done by defining the rolling moment and roll rates as accurately as possible during the wind tunnel separations and comparing those values (scaled to full scale) with the estimated capabilities of the control system.

There were about 70 trajectories performed during this test with no separation problems encountered. During several trajectories, rather high roll rates were experienced, but all were determined to be within the capability of the control system. These data were instrumental in obtaining clearance for flight tests during which four launches were made with boilerplate aerodynamic test vehicles (BATV) of HARPOON. These flight tests provided data for correlation with the wind tunnel results.

The flight test plan called for two drops at a low dynamic pressure, a condition expected to produce the greatest pitching motion, and two drops at high dynamic pressure which was expected to produce the highest roll rate. Due to either data collection problems or a mismatch in launch conditions, there was only one flight for which wind tunnel data was available. This launch was from the inboard pylon with a 300-gallon tank on the outboard station at an altitude of 3,050 ft in straight, level flight at Mach 0.79. The mass properties of the BATV were similar to the design properties of the HARPOON; however, the moments of inertia were slightly low and the center of gravity was more forward making the vehicle more stable. This condition was chosen for a repeat run during the wind tunnel test giving another set of data for correlation.

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Figures 2, 3, and 4 present the data for runs 25 and 45 of the CTS test and the flight test results from the BATV-4 drop. The data selected for presentation are considered to be representative of the data taken and show all significant motions during separation. In Figure 2 near perfect agreement is seen for the vertical displacement during separation. Some disagreement is seen in pitch angle; however, there are several factors that could contribute to this disagreement. Table 1 compares the inertia properties of the BATV and the properties used in the CTS test. Several characteristics would contribute to data mismatch. First the more forward c.g. location of the BATV increased stability causing a faster response to pitch distrubances and, in addition, the lower moment inertia adds to this higher response. These two effects produce a stiffer system in pitch and increase pitch rates.

The correlation of data in the yaw plane is shown in Figure 3. Generally, these data compare favorably. Agreement of the repeat runs during the wind tunnel test appears to be very good with some slight differences with flight test data in the spanwise displacement. The data for yawing motion correlate extremely well.

As mentioned, the high Mach number (high dynamic pressure) conditions were chosen because these should produce the highest roll rates for the HARPOON during separations. As can be seen in Figure 4, high roll rates and significant roll displacements were experienced. The rolling motion showed the greatest disagreement between CTS and flight test data with the flight test producing significantly higher roll rates and, therefore, higher roll angles than the windtunnel test. Although the moment of inertia of the BATV was low, that difference was not enough to account for these large differences. The flight test data show a very high roll acceleration at initiation of the launch indicating large rolling moment in the stowed position. During the wind tunnel test it was noted that very high gradients in the rolling moment near the stowed position were present. Therefore, slight differences in the spacing from the pylon at launch could account for the disagreement in these data. In addition, due to the small scale the magnitude of the rolling moment produced by the wind tunnel model was very difficult to read. Because these moments were small compared to the balance capabilities, some inaccuracy was expected.

In general, very good agreement was shown with this limited amount of data. The correlation was especially good for those motions critical to safe separation (vertical dispalcement, pitch, and yaw motion). The data seem to support the contention that special care needs to be taken to reproduce the conditions at launch as faithfully as possible to ensure a true representation of the launch trajectory.

SEPARATION STUDIES OF THE BQM-74C

In an effort to expand training capability at sea, the ground-launched, MQM-74 target vehicle has been modified for carriage and launch from aircraft. The air-launched configuration, BQM-74C, was designed for use on several Navy aircraft, including the A-6 and A-4, to provide the fleet with launch platforms that would be available at sea. This would minimize the need for support from land-based aircraft during practice exercises. Since this target vehicle is relatively lightweight and has a high wing loading, separation characteristics were of concern. In addition, rolling moments created by flow on both aircraft

needed to be investigated to ensure that they did not present problems for the control system. The flow around the A-6 wing stations has caused rolling moments for other stores, and the carriage position on the A-4 places the target's outboard wing in front of the swept leading edge of the aircraft wing causing rolling moments due to gradients in the upwash. Although the roll control system is active during separation, the limit of its effectiveness was an area of concern. To simulate the roll control system, the store was not allowed to roll; however, the rolling moments were recorded and these moments were compared to the control system capabilities.

The primary objective of this program was to define a safe separation envelope for the flight test program. A range of flight conditions were run to cover the Mach number/altitude region to be used for launch. Most trajectories were started from level flight with thrust on the BQM-74C and with several pitch control surface settings. The study of control surface settings provided guidelines as to what conditions allow the safest launch envelope.

This program started with a captive trajectory system study of the BQM-74C from the A-6E aircraft, using 6.25-percent scale models in the 7- by 10-foot transonic wind tunnel. Generally, the first part of any CTS program is a comparison of store model data with isolated aerodynamic data. In this test, an unexpected problem was encountered when the isolated data were examined. As can be seen in Figure 5, when data without grit is compared with predicted data, the normal force was non-linear and the agreement of pitching moment data was poor. Several possible causes for this nonagreement were examined (mechanical slippage, data system and data reduction errors) to no avail. Once data problems were ruled out, aerodynamic causes were investigated, model buildup data were taken, and the problem was narrowed to the horizontal tail surfaces. The traditional methods for boundary layer trip did not hold for such small surfaces; therefore, some experimenting was done. The solution that came from this was to apply transition grit lightly over the entire tail surface. The data obtained with this change are also shown in Figure 5. In the test program with the A-4 aircraft, a 10-percent model was used, and similar problems were encountered. The same approach again produced data that agreed with previous results.

After obtaining satisfactory isolated data, approximately 36 trajectories were run on each aircraft. The conditions for these trajectories were spread over a range of Mach numbers and altitudes to cover the entire launch envelope. The objective was to show safe separation and determine pitch control settings that provided good separation characteristics. The majority of the trajectories were run with thrust on the BQM-74C and the roll control system simulated by not allowing the store to roll. A few runs were made with no thrust and roll permitted. These runs were to simulate an emergency jettison condition or a failure of the control system.

Figure 6 presents typical data from the CTS study. These data show the effect of control deflections for a launch from the A-6 outboard wing station. The conditions for these data were the worst encountered during the test with low altitude and high dynamic pressure. As can be seen, a 3 deg deflection to give the store a nose-down pitching moment is sufficient to provide safe separation.

The other area of investigation, jettison conditions, proved to be equally successful. The concerns here were two-fold. Without an active control system, the store may roll a wing or tail surface into the pylon or with no pitch control deflection the store may fly into the aircraft. The data show that neither of these events occur. The store cleared the pylon before the roll angle was high enough to hit the aircraft, and with the high roll angles the lift vector is rotated to where the store did not exhibit any motion toward the aircraft.

The trajectory data from the test of the A-4 show equally safe separations. In the stowed position, rolling moments were higher than those on the A-6; however, since the store was not allowed to roll (control system simulation), the trajectories were not affected. These rolling moment were expected since in the stowed position the outboard wing of the BQM-74C was forward of the A-4 wing leading edge, placing that wing more into the upwash of the wing. These rolling moments decreased rapidly as the store dropped from the aircraft. As on the A-6, the jettison tests show that the rolling moments cause enough roll to prevent the development of high forces that would lift the store back toward the aircraft. However, the ejector produced enough acceleration to have the store clear the aircraft before the roll produced any collision.

PRESSURE SURVEY OF A-6

In an effort to analytically study the separation of stores from the A-6 aircraft, a mathematical model of that aircraft was developed. To verify the validity of this model, experimental data were needed for comparison, and very little wind tunnel testing relating to store separation had been done on the A-6 aircraft. Therefore, it was desirable to obtain basic flow field data for correlation with analytical predictions.

Using a flow angularity probe mounted on the support system, a grid of points were surveyed beneath each station on the left wing and centerline in the station plane at the points illustrated in Figure 7. Data were taken at these points for two Mach numbers and two angles of attack, with and without pylons. From these data, velocity pertubations were computed throughout the flow field.

Figure 8 presents a sample of these data taken at the inboard wing station with the pylon in place. As can be seen, expected trends are present in these data, and a limited amount of correlation has shown good agreement; however, additional work is needed.

FUTURE PLANS

Throughout these testing efforts, improvements have been made to the equipment and operating procedures. However, there are several additional changes that are planned which will increase utility and versatility of these test techniques.

The primary link in the improvement process will be the conversion to a new computer system. The software for CTS operation is now limited by memory capacity of the computer being used, but conversion to a new machine will eliminate this problem. This greater memory capacity will allow control systems to be added to the CTS software as well as permit improved printout and data handling. This new equipment will have graphics capability, and plans are being made to make use of this feature.

The new computer system will also allow *other improvements* in the operating software. By expanding the software, several optional packages will be selectable ranging from CTS operations to automated collection of isolated data on the store. With the peripheral equipment available, the handling of input constants will be streamlined to improve testing efficiency. In addition, software will be developed to improve procedures for doing sting deflections and balance check loading, shortening installation time considerably. In converting the basic CTS software for the new computer system, major improvements will be *made in the operations* of the computer/CTS system which will streamline the interface between the operator and the equipment. The system will be more automated such that less input from the operator is necessary; however, increased information for monitoring the operations will be made available. This will allow the system to work more efficiently and yet provide engineers with more data to judge performance during testing.

In addition to these major changes, smaller improvements are planned for the support system that will increase versatility of all the testing techniques. Changes to the mounting system for the parent model are planned which will allow easier access to various positions *on the model.* Relative motion due to wind tunnel air loads have caused problems in the past. Several improvements are being sought that will solve these problems.

REFERENCES

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3. Maddox, A.R. R.E. Dix and G.R. Matasitis, "In-Flight Measurements of Captive Loads on a Store as Compared with Wind Tunnel and Mathematical Simulations," Naval Weapons Center TP 6026, China Lake, California (Apr 1978).

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6. McCabe, E.F. Jr.,and D.W. Lacey, "Aerodynamic Feasibility for Airborne Retrieval of a Remotely Piloted Vehicle," David Taylor Naval Ship Research and Development Center Report 76-0043, Bethesda, Maryland (Nov 1976).

TABLE 1 - HARPOON TEST CONDITIONS

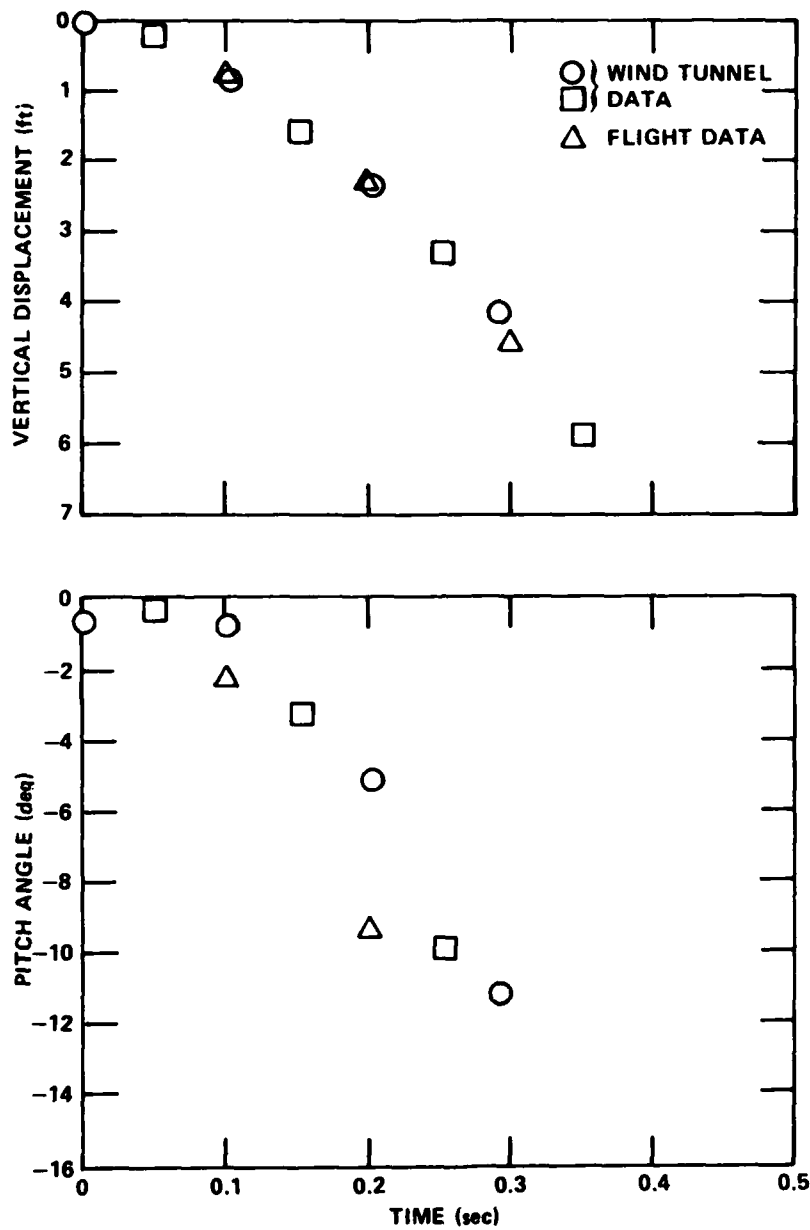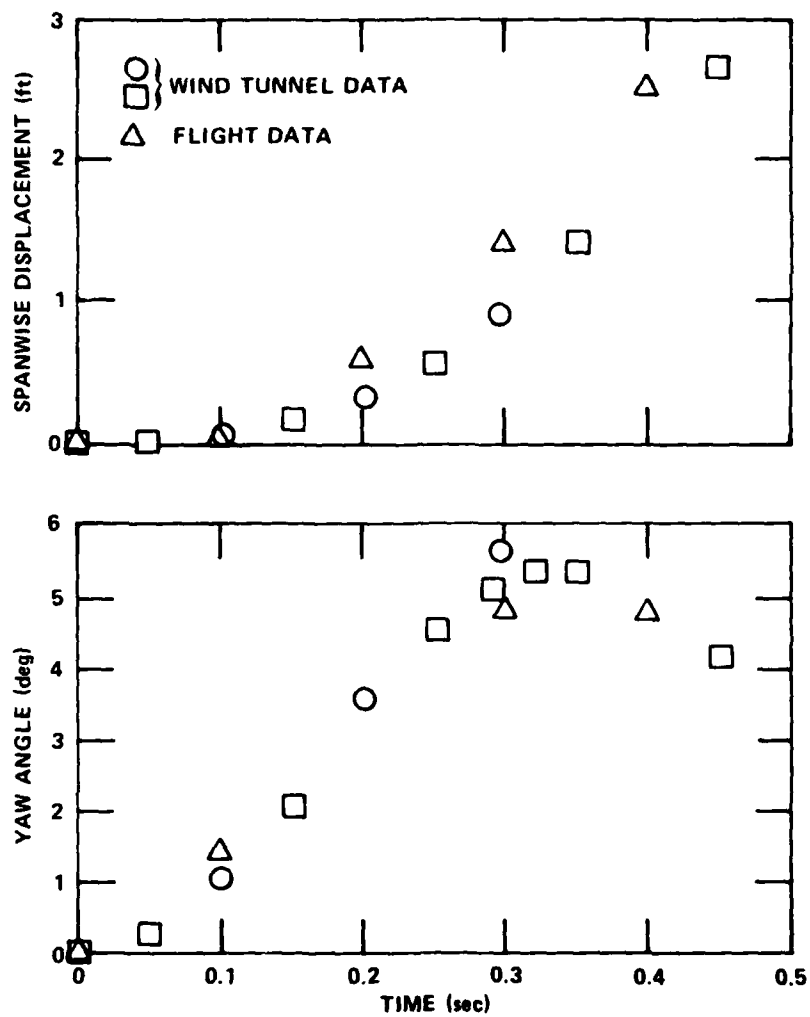| PARAMETERS	FLIGHT TEST	WIND TUNNEL TEST
Altitude (ft)	3050	2993
Mach No.	0.79	0.80
C.G. Position (MS)	83.03	83.08
Inertia (slug-ft^2)		
X	6.4	6.9
Y	340.2	360.9
Z	342.2	360.7
Weight (lbs)	1149	1145

Figure 1 - Typical GTS Installation

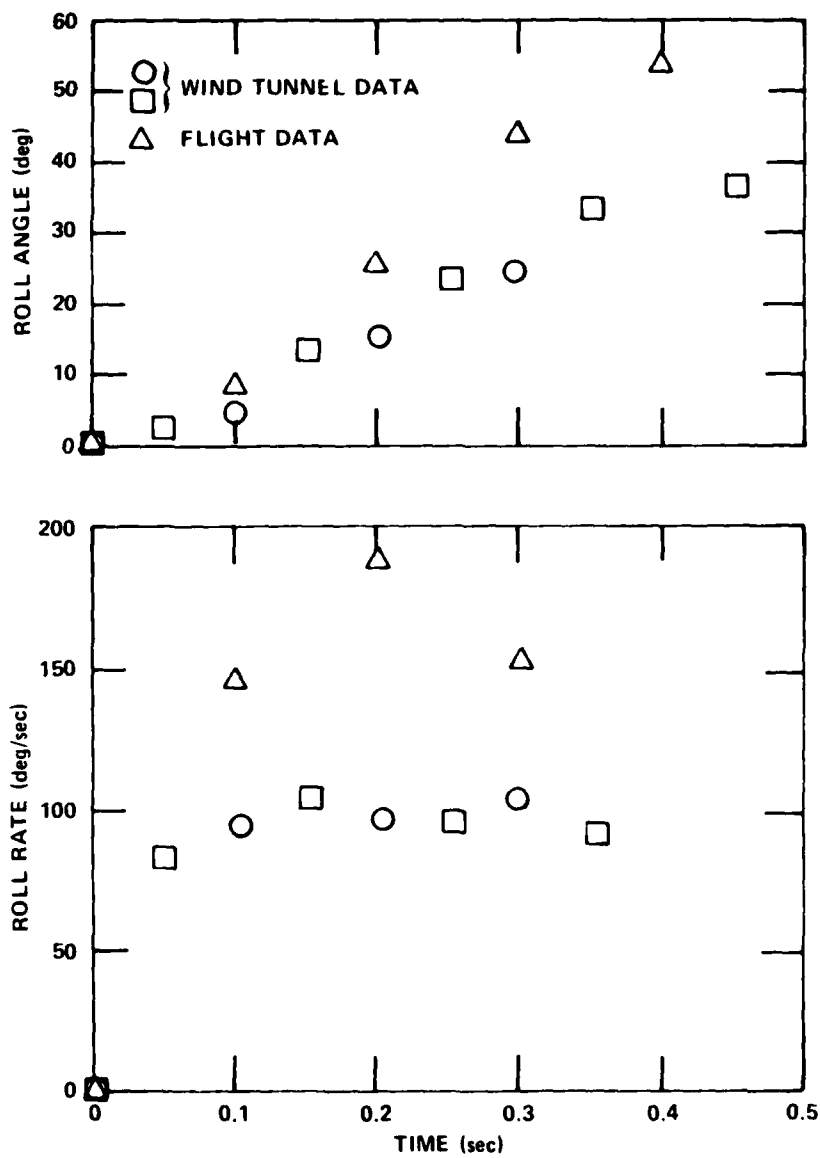Figure 2 - Pitch Plane Motion
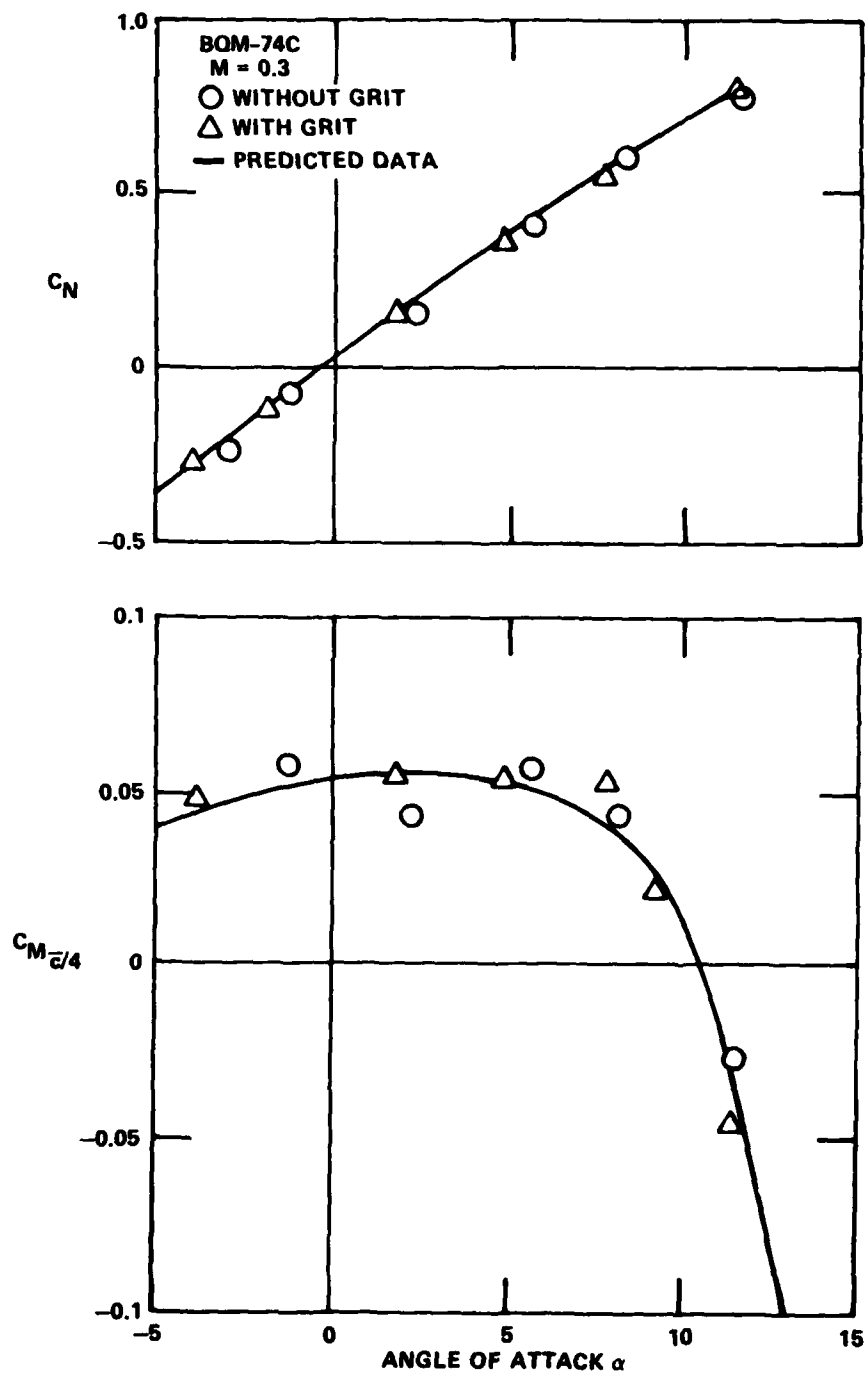
Figure 3 - Yaw Plane Motion

Figure 4 - Roll Motion

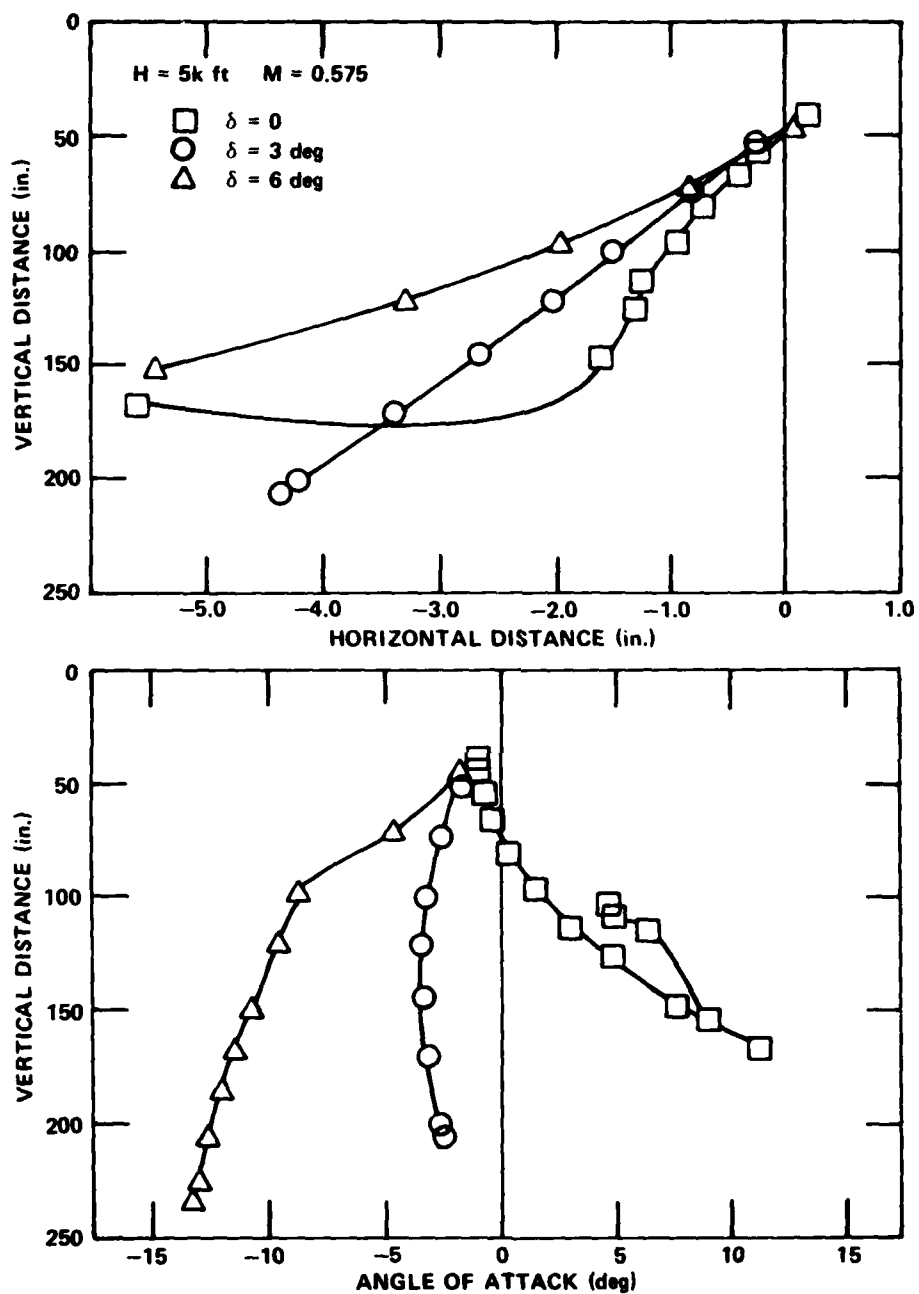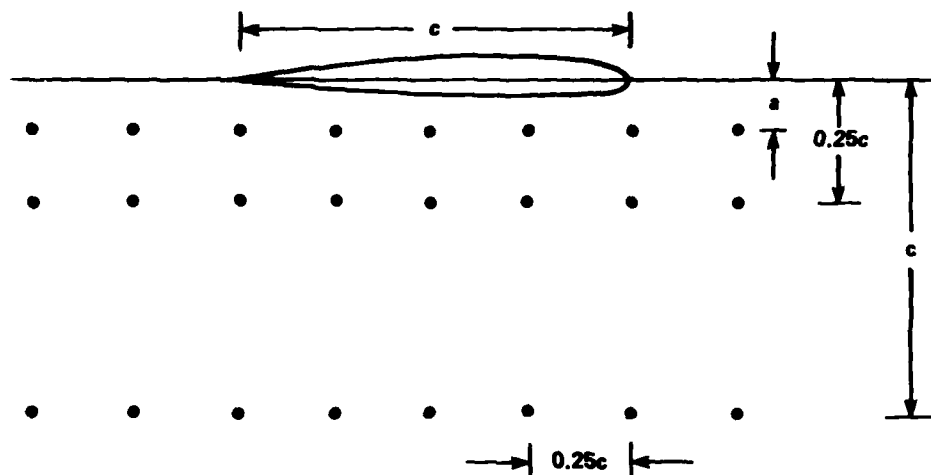Figure 5 - Isolated Data for BQM-74C

Figure 6 - Effect of Control Deflection on Separation
Characteristics of BQM-74C

c – LOCAL CHORD LENGTH

a – DISTANCE FROM WING PLANE
  TO THE CENTERLINE OF A
  MK-81 ON THE PYLON
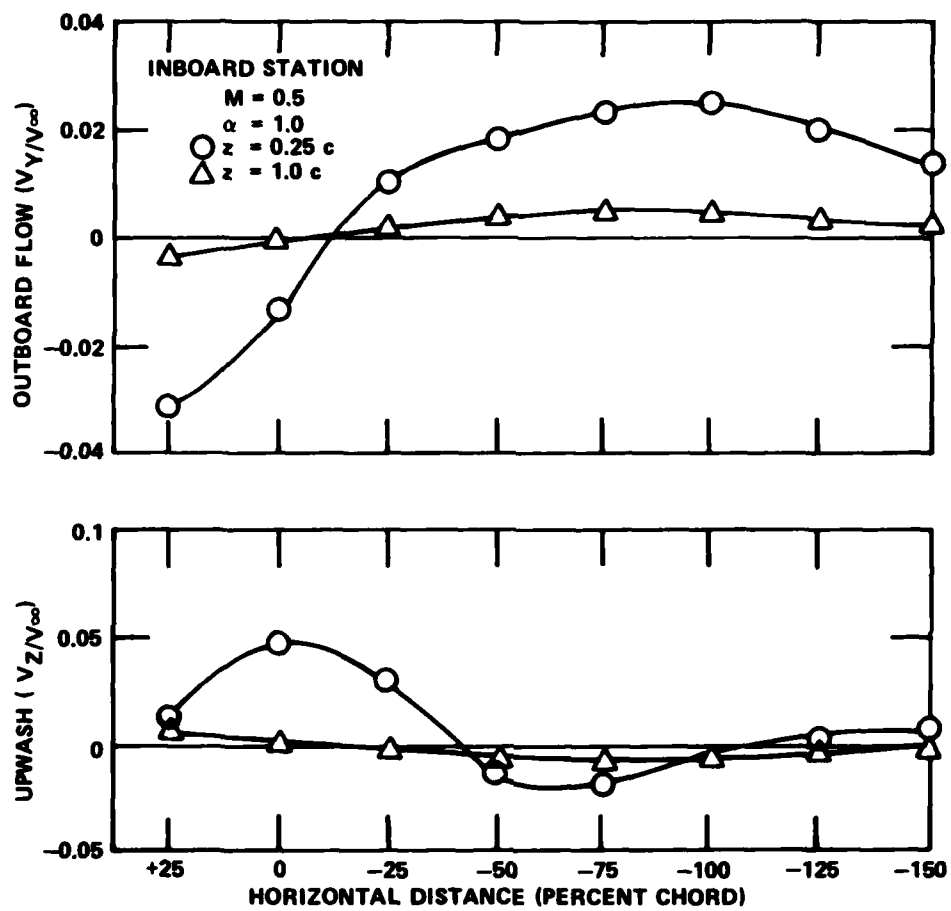
Figure 7 – Pressure Survey Grid

Figure 8 - Perturbation Velocity Beneath A-6 Inboard Pylon

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